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Sustainable urban infrastructure management: integration of urban computer modelling

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Structured Abstract

Purpose – This paper seeks to examine the complex relationships between urban planning, infrastructure management, sustainable urban development, and to illustrate why there is an urgent need for local governments to develop a robust planning support system which integrates with advance urban computer modelling tools to facilitate better infrastructure management and improve knowledge sharing between the community, urban planners, engineers and decision makers.

Design/methodology/approach - The methods used in this paper includes literature review and practical project case observations.

Originality/value – This paper provides an insight of how the Brisbane's planning support system established by Brisbane City Council has significantly improved the effectiveness of urban planning, infrastructure management and community engagement through better knowledge management processes.

Practical implications – This paper presents a practical framework for setting up a functional planning support system within local government. The integration of the Brisbane Urban Growth model, Virtual Brisbane and the Brisbane Economic Activity

Monitoring (BEAM) database have proven initially successful to provide a dynamic platform to assist elected officials, planners and engineers to understand the limitations of the local environment, its urban systems and the planning implications on a city. With the Brisbane's planning support system, planners and decision makers are able to provide better planning outcomes, policy and infrastructure that adequately address the local needs and achieve sustainable spatial forms.

Keywords – Knowledge management, Computer simulation models, Brisbane Urban Growth (BUG) Model, Virtual Brisbane

Paper type – Research Paper

1 Introduction

Sustainable urban development and the liveability of a city are increasingly important issues in the context of land use planning and urban infrastructure management. Urban infrastructure is an important part of a city and a vital component of a complex urban system which is essential to support any urban developments.

In recent years, the promotion of sustainable urban development in Australia and overseas is facing various physical, socio-economic and environmental challenges. These challenges and problems arise from the lack of capability of local governments to accommodate the needs of the population and economy in a relatively short timeframe. The planning of economic growth and development is often dealt with separately and not fully included in the conventional land use planning process. There is also a sharp rise in the responsibilities and roles of local government for infrastructure planning and management under the pressure of rapid urban growth. Aside from managing the daily operational functions of a city, such as assessment of property development applications and maintenance of urban streetscapes, local governments are now also required to undertake economic planning; manage urban growth; be involved in major national and state infrastructure planning and even engage in achieving sustainable urban development objectives.

The increase in the responsibilities and roles of local governments have meant that local elected officials and urban planners have less time to make decisions, and so rely more on planning support systems that inform the decision making process and improve urban management practices. Planning support system has the capability of improving the handling of knowledge and information in planning processes. Better handling of knowledge and information means that urban planners and engineers should be more capable of handling the ever-increasing complexity of planning tasks.

In spite of the potential benefits, the use of planning support systems in planning practice is limited to the use of urban computer simulation models and spatial mapping programs. Many of these models and programs are generally 'one-off' applications with a single purpose, rather than multi-dimensional applications. As a result, many of them become obsolete in a relatively short period of time. A major problem contributing to the development and implementation of the planning support systems is the lack of understanding of complex relationships between urban planning, infrastructure management, and sustainable urban development of a city.

The aim of this paper is to examine the complex relationships between urban planning, infrastructure management, sustainable urban development, and to illustrate why there is an urgent need for local governments to develop a robust planning support system which integrates with advance urban computer modelling tools to facilitate better infrastructure management and improve knowledge sharing between the community, urban planners, engineers and decision makers.

The development of the Brisbane Urban Growth (BUG) Model, Virtual Brisbane (3D visualisation model) and Brisbane Economic Activity Monitoring (BEAM) database have proven initially successful for Brisbane City Council as the first step toward establishing a sustainable urban and infrastructure management framework. This new framework which integrates with advance urban computer models has significantly improved the effectiveness and efficiency of urban planning and infrastructure management. It is a better approach to facilitate sustainable urban development and infrastructure management than conventional land use planning approach alone.

2 Urban planning and urban infrastructure management

In the early 1950s, the term 'urban infrastructure' referred mainly to buildings and other permanent assets such as road and water networks (Gleeson, Dong, & Low, 2007). The definition of urban infrastructure has expanded since the 1960s. The term 'urban infrastructure' can now refer to many services, depending on the context in which it is used (Gleeson et al., 2007). It can generally be classified into physical and social infrastructure. Physical infrastructure, commonly known as 'hard infrastructure', includes stormwater drainage; roads and transport facilities; telecommunications facilities; water and sewerage facilities; and other networked services (Gleeson et al., 2007). Social infrastructure, commonly known as 'soft infrastructure', includes educational and health care facilities; sport and leisure facilities; law and order; and public administration (Gleeson et al., 2007).

Contemporary land use and urban planning originated from the industrial revolution that began in the 1850s. Planning by public authorities was used as a tool for improving the health of the working population due to epidemics, water contamination and urban slums. The main reason for this action was to improve the health conditions of labour workers so that they could work harder and at the same time reduce the cost of supporting an unhealthy labour force and their families (Friedmann, 1987; Hall, 2002; Sies & Sliver, 1996; Taylor, 1998). Gradually local authorities took responsibility for providing urban infrastructure such as clean water, and the removal of domestic waste such as sewerage and garbage. Physical land use planning was used mainly to enable the separation of residential developments and industrial activities.

In modern times, greater emphasis on the decentralisation of urban governance structures has meant that the traditional roles of local governments in managing basic land use, infrastructure and services are no longer sufficient to meet the local community needs. Local governments are now increasingly involved in regional and national strategic planning initiatives and programs such as regional economic development, major road and public transport infrastructure projects, and management of urban growth (Atterton, 2007; Haywood, 2005; Stren, 1993; Worthington & Dollery, 2000).

As a consequence of more demand on local government in managing legislative requirements and meeting community needs, the roles of land use and urban planning had also evolved rapidly in the past several decades (Byrnes & Dollery, 2002; Cetinic-Dorol, 2000). Urban planners are now required to provide strategic advice on many urban growth and infrastructure management issues ranging from rezoning of land for community use to strategic distribution of public transport routes and infrastructure. Due to the demand on greater linkages and accountability between different projects, planners can no longer deal with such issues in isolation.

Contemporary land use planning approach such as land use zoning plans is often based on historic trends and abstract values without a total understanding of the urban environment and its systems (Brisbane City Council, 2008). It has been suggested that there is a constant mismatch between what is a planner's view of a desirable spatial outcome and the realities of the evolving urban structures. Such a mismatch is a result of our limited understanding of localised urban patterns (Forster, 2006; Gleeson & Randolph, 2001). Therefore, this brings forward the concept of developing an effective planning support system which integrates with advance urban computer models in the context of sustainable urban development and infrastructure management.

3 Knowledge management and the rise of urban computer modelling

Our urban environment is becoming increasingly complex and large in scale as local urban economies, social and political structures, transportation systems, and infrastructure requirements evolve. The sustainable and efficient usage of scarce resources, together with competing economic and social priorities, are now parts of everyday decisions required to be made by local governments (Andersson, Frenken, & Hellervik, 2006; Baccini, 1997; Berliant & Wang, 2004). Many mathematical, engineering and theoretical models have been used to attempt to develop an understanding of some aspects of urban systems, its structure, and its interconnection relationships (Fragkias & Seto, 2007; Jat, Garg, & Khare, 2008).

Knowledge management is an evolving discipline that has garnered interest from both academicians and practitioners. The early years of knowledge management were characterised by the development of computer database that stored information and knowledge (Sasson & Douglas, 2006). The use of geospatial, computer visualisation and simulation models as knowledge management tools to assist policy making, urban planning and management is not a new concept. Modern computer simulation models have been widely used in developed countries to evaluate major public and private urban development projects and forecast development patterns (Cheng & Masser, 2003; Ward, Stimson, & Murray, 2001; Wilson, Hurd, Civco, Prisloe, & Arnold, 2003). The steady expansion of local governments' responsibilities as mentioned in earlier sections has also resulted in the development of multi-modal approaches to urban and transportation modelling, including mode choice, travel demand management, land use policies change, working hours, and congestion pricing (Marinoni, 2005; Waddell & Ulfarsson, 2004).

Current best practices in search of attaining integrated urban infrastructure management predominantly focus on the development of robust and integrated planning support systems which integrate advance computer simulation and visualization models to inform and enable greater public and private sectors engagement in the decision making process. The states of Oregon and Florida, for example, have implemented containment strategies with the use of robust land use and planning support system to inform urban planners and decision makers on the effectiveness of existing land use policies (Boyle & Mohamed, 2007; Nelson, Burby et al., 2004; Nelson, Dawkins, & Sanchez, 2004).

As a result, decision makers have better knowledge and information and were able to regularly evaluate the impacts of their urban management policies, particularly in relation to the efficiency of public transport systems and other development infrastructure to meet the demand of urban growth. Nonetheless, current research on integrated infrastructure management to date have not fully explored the potential of a robust planning support system that can be further developed and integrated into local government authorities to facilitate sustainable urban growth and infrastructure management outcomes (Carnegie & Baxter, 2006; Hohn & Neuer, 2006; Mattingley, 1994; Reddel, 2002; Worthington, 2007).

An integrated planning support system for urban infrastructure management would have the potential to provide outcomes to evaluate land use policies, but also to be integrated into local government systems to inform corporate decisions making regarding estimates and benchmarks, future cost recovery of infrastructure charges, and human resource needs.

4 Planning support system and urban infrastructure management

Brisbane is anticipated to grow rapidly into the next 15 years as one of the fastest growing cities in the South East Queensland region of Australia. Various scales of brownfield redevelopment are already in progress. It is expected that the rate and scale of brownfield redevelopment will intensify further as the last remaining greenfield land in Brisbane will be fully developed while Brisbane continues to grow strongly as a major economic capital. At present, various planning documents set out planning priorities for Brisbane including urban renewal, neighbourhood plans, Transport Orientated Developments (TODs), major transport projects and other major developments. All these projects are closely related and urgently require an integrated framework to ensure that land use planning, local economic development and infrastructure provision is delivered to meet the needs and demands generated by the anticipated economic and population growth.

The unprecedented urban growth has prompted Brisbane City to develop a robust planning support system to provide strategic directions to planners and decision makers on the anticipated sequence and scale of future development clusters. The introduction of the Brisbane Urban Growth (BUG) model, Brisbane Economic Activity Monitoring (BEAM) database and Virtual Brisbane (3D visualisation model) by Brisbane City Council has successfully revolutionised the approach to forecasting developments and the planning of urban infrastructure.

4.1 Brisbane Urban Growth (BUG) Model

The BUG model is an advance oracle database linked to a GIS analytical and visualisation interface for analysing and identifying future development and its development sequencing (Brisbane City Council, 2008; Lau & Lister, 2006; Lister, 2004). Its prime data is extracted from the local government rate database. Local environmental constraints such as slope gradient, flooding and waterways corridors are included into the BUG model. The BUG model uses the information in the spatial database as well as other development factors such as property value, land value and conversion rate, to forecast development potential at property level for the city (Brisbane City Council, 2008). The model BUG model also uses information in the BEAM database to evaluate and forecast the demand for non-residential uses.

An improved version of the BUG model is currently being developed by Brisbane City Council. This new version has improved functionality to forecast non-residential and mixed uses development. This new version also uses new model simulation algorithm and integrate with the latest multi-modal transport accessibility model. The BUG model with its improved functionalities is anticipated to be the fundamental tool to assist planners to understand the limitations of the local environment, provide details local knowledge of the planning implications for a city. The results of the model outputs enable planners and decision makers to provide better planning, policy and infrastructure that adequately address the local needs and achieve sustainable outcomes and spatial form.

Figure 1 illustrates the conceptual framework of the latest BUG model. The operational framework of the BUG model consists of a variety of urban and property development factors as well as transport accessibility factors to ensure the maximisation of future urban development along public transport nodes and corridors. The BUG model focuses on supply side information, uses a detailed bottom-up growth forecasting approach and provides a triple bottom line sustainability planning and policy approach for its municipal government. The Sub Lot Calculator uses information from the development factors and constraint data to generate potential development options for each parcel. The Development Option Evaluator then evaluates each option and determines which option will have the potential to generate a better development return.

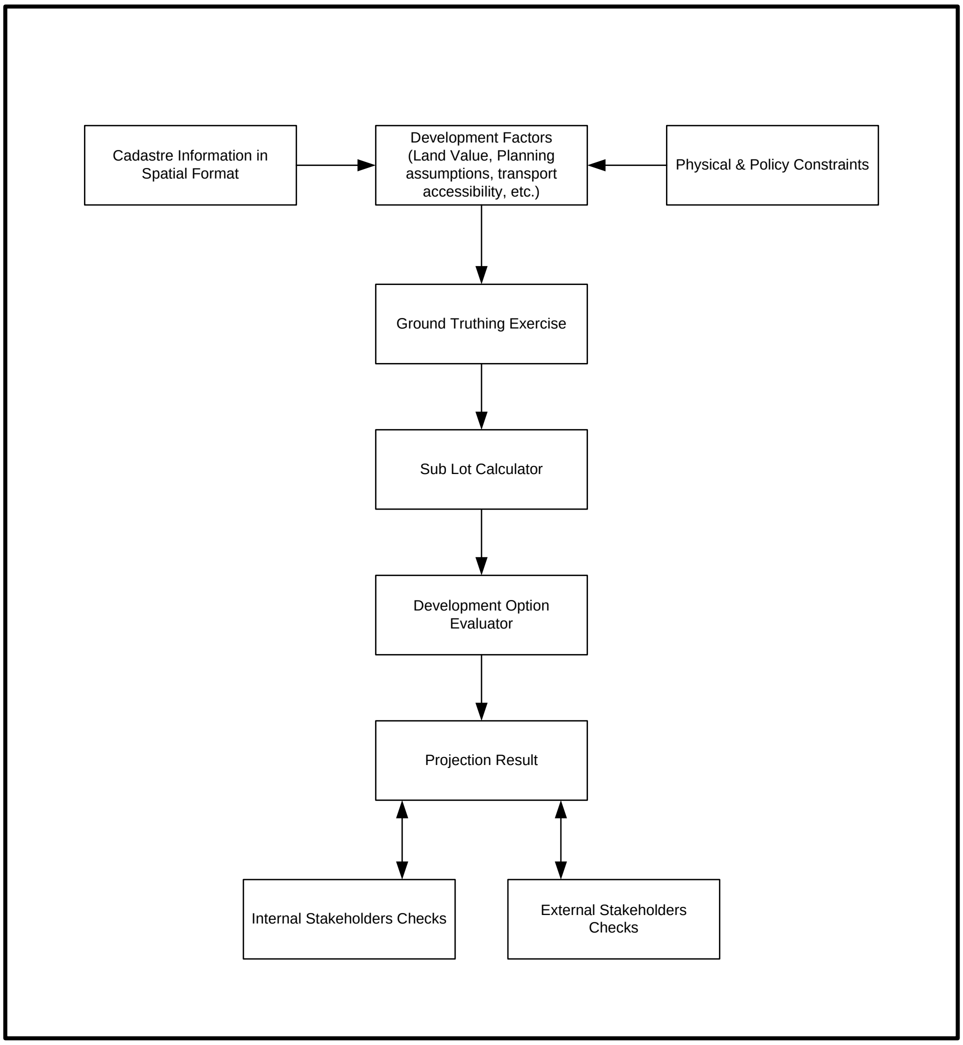

Figure 1: Conceptual framework of the BUG model.

In contrast to the conventional top-down rational comprehensive approach which focuses on delivering its objectives, the bottom-up approach focuses on exploring the local limitations, understanding the interconnection relationships between the urban systems and establishing sensible realistic solutions to revolve issues (Sabatier, 1986). However, this type of approach may not be the most time efficient method for solving urban growth issues at a citywide level. The alternative to this approach is the collaborative or joined-up approach which utilises the strengths of the top-down and bottom-up approaches.

4.2 Brisbane Economic Activity Monitoring (BEAM) Database

The BEAM database is an occupancy database. It was originally created to monitor and track the progress of the non-residential activities across the city of Brisbane. In particular, it was established to monitor the variety of commercial and retail activities within shopping centres. The monitoring of the business occupancy was first started in 2007, with over 22 of Brisbane's Activity Centres being surveyed. The data is stored in a spatial database which can be easily integrated with other spatial databases. The detailed information obtained through the survey has provided useful background data to support the planning of local community and urban infrastructure. The BEAM database is now also integrated with the BUG model to enhance the model's ability to forecast non-residential developments.

4.3 Virtual Brisbane

From the introduction of computer graphics, the demand for visualisation techniques has grown continuously (Fritsch & Kada, 2004). The 3D visualisation industry continues to experience rapid expansion from architecture, to the gaming industry, the medical industry and feature films. Industry growth combined with software and hardware evolution has lead to the steady improvement of the production of 3D visualisation. "Visualisation is considered as much more than creating realistic images of what is or what might be, and much more than creating attractive charts and maps. Visualisation is concerned with foraging for data in a data rich environment made much more accessible by the World Wide Web. It is involved with transforming data to information, to knowledge, and into action" (Langendorf, 2001).

There are numerous visualisation tools available for decision makers, urban planners and community users to review, evaluate and simulate planning scenarios. These systems typically rely on the use of GIS maps, charts and technical reports to display the outputs or the consequences, but it is still insufficient for many non experts to fully understand spatial or scientific information. (Duy, 2008). Early planners created city models with cardboard from elaborate manual methods, while visually powerful were limited in the level of interactivity; 3D visualisation now offers a powerful and emersive tool for creating and visualising digital models of cities (Hu, You, & Neumann, 2003). Visualising urban design landscapes in a collaborative virtual environment is now a popular trend in the portfolio of urban planning literature. This requires the utilisation and integration of GIS, urban planning tools and 3D visualisation systems. Such systems demand sophisticated data conversion and intensive computation to transform a wide range of spatial data formats into the 3D data standards of various visualisation systems (Duy, 2008).

It is believed that technologies such as 3D geographical visualisation can assist planners in better communicating planning outcomes to decision-makers and to engage the public, and thus make better collective spatial planning decisions (Pettit, Cartwright, & Berry, 2007).

Until November 2006 Brisbane City Council maintained in its Central City Library a basic cardboard 3D model of the CBD area for the display of major Development Application proposals and approvals in the CBD. In subsequent years, the model fell into disrepair and it was not considered worthwhile to carry out expensive repairs. Investigations proceeded into securing a computer-generated 3D model to replace the physical model. The move to a digital model was supported to enable Council to integrate with other agencies using 3D modelling and to respond to regular lobbying from the development industry for access to such a facility. Research identified that the standard and capacity of available technology for digital 3D modelling varied widely, with many potential suppliers in the market. Similarly, the pace of change in the digital modelling industry was and continues to be rapid, as model builders leverage off beneficial synergies with complementary technology such as computer gaming and digital photography.

A proposal was presented to Civic Cabinet along with a brief display of examples of currently available digital modelling. Strong support was immediately offered for the project to commence, under the stewardship of the Urban Futures Brisbane Board, Council's independent advisory board on planning issues. The project was initiated from a competitive tender process for 3D built-environment modelling. Thus the Virtual Brisbane project was given its genesis.

The Virtual Brisbane 3D model is captured and created accurately from an aircraft mounted Pictometry multi-oblique 3D camera system providing a snap-shot in time which can be progressively updated providing an easy-to-access and centrally-located master record of the urban development activity across the inner city. Utilising Photogrammetry technology provides a visually accurate record unlike other simulated-textured models. Photogrammetry is a cost-effective means of obtaining large-scale, spatially accurate urban models. The technique utilises aircraft captured 2D images combined with LIDAR laser scanning to produce the 3D terrain and building models. The dataset provides an easy-to-access and centrally-located master record of the urban development activity across the city and urban areas.

The fully-textured 3D model features every building and structure in a 5km radius around the CBD and other extension areas including Chermside, Indooroopilly, Upper Mt Gravatt and the Racecourse Road Neighbourhood Planning Precinct. The model spans an area of approx 100 sq km, and is the largest 3D city model in the southern hemisphere. The model is able to be used in an interactive way to visualize the existing urban environment as well as new planning strategies and development proposals in a real-world scenario.

The model software is based on The Open Scene Graph (OSG), a cross-platform C++ / OpenGL library for real-time visualisation. It has become a powerful alternative to traditional tools like Performer and is freely available (Fritsch & Kada, 2004). The library not only features high performance rendering capabilities and excellent support for PC graphics accelerators, but also offers stereo mode and a broad variety of loaders for many common data formats. The software offers the ability to page large 3D model datasets with varying level of texture detail for optimised navigation. For the purpose of moving through the datasets, there exist camera manipulators that simulate movement in a car or in an airplane. The drive camera manipulator even uses collision detection so that the virtual vehicle stays on the ground. OSG has been successfully used in non-commercial games and virtual reality applications (Fritsch & Kada, 2004).

Outputs from the Virtual Brisbane 3D model include High definition still imagery and animation flight-paths. It has the ability to produce Real-time shadow analysis of the entire scene or individual objects depending on the position of the sun in real-time. The model also has the capability to undertake Real-time visibility analysis, allowing the calculation of visibility from point to point in the 3D scene. 3D CAD models can be linked to GIS datasets to display polygons, line-work and lookup table information visually in 3D. This provides not only a visualisation tool but complete integration with 3D modelling and GIS datasets. This combination provides a visually powerful tool with a wider range of potential applications than a static 3D model. Figure 2 illustrates an example of the Virtual Brisbane still imagery output of one of the future land use scenarios of the city.

Figure 2: Land use scenario still imagery example of the Virtual Brisbane.

Virtual Brisbane provides residents with the ability to participate in decision-making for local neighbourhood areas by enabling the visualisation of different development scenarios in an intuitive manner based on the resident’s human perception of the built environment (three dimensional spatial perceptions). This helps Council plan for future development and identify practical and attractive designs for various projects. Development projects become easier to understand along with the changes that could occur in their city and the planning outcomes that can be achieved. Virtual Brisbane provides an effective way to visualise future land use and development patterns in an intuitive manner which are traditionally presented on a piece of paper. Virtual Brisbane is now an important part of Brisbane City Council's urban planning processes. It has been successfully used on a range of planning projects such as neighbourhood plan, River City Blueprint and city's new strategic plan. It also helps urban planners, engineers and city architects for the visualisation of proposed developments and scenic amenity in the development assessment process.

5 Planning support system and the integration with urban planning process

Over the last two decades, cities in Australia and overseas are taking a range of innovative sustainability initiatives to ensure that each step of the urban development process contributes to a reduction of the ecological footprint and to an improvement in the quality of life (Jones, 2005; Stimson & Simpson, 2001). Rational comprehensive planning is still one of the most influential urban planning methodologies in Australia and overseas (Gleenson & Low, 2000; Rosenhead, 1980). Many of the existing growth management approaches and policies are developed using this methodology. In this approach, urban planners and decision makers are making their rational decisions based on abstract values. These values are generally presented as agreed consensus and higher level agencies can expect the compliance of lower level agencies with their decisions (Rosenhead, 1980). This top-down approach emphasises management, measurement and control. But it often disregards local limitations, constraints and other externalities because its decisions are based on a set of abstract values (Sabatier, 1986).

Figure 3 illustrates the conventional local government process used by Brisbane City for the planning and delivering of urban infrastructure under a top-down approach. In this approach, the planning of infrastructure is often seen as a discrete exercise among different infrastructure providers. Planning studies are often carried out to justify a pre-made decision or objective, rather than to provide a factual recommendation.

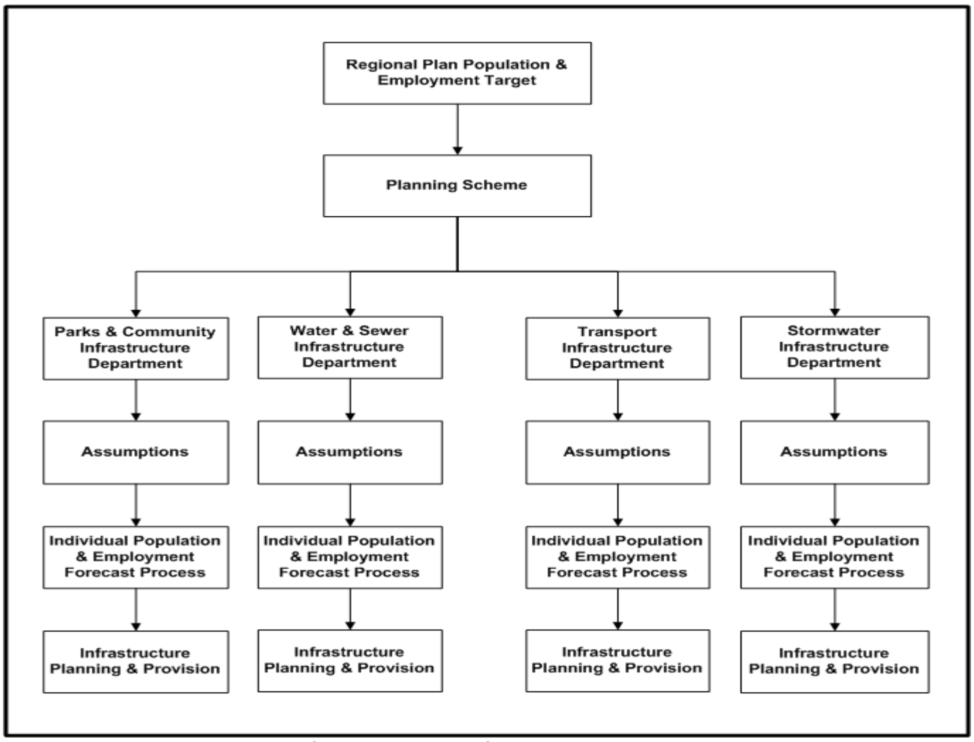

Figure 3: Typical approach for delivering infrastructure in local government, derived from (Brisbane City Council, 2008)

Urban planning, infrastructure provision and management should be based on reliable information, knowledge and good understanding of the urban systems and their interconnected relationships. A good planning support system has to integrate with practical planning process. The new urban planning and infrastructure management framework used by Brisbane City Council has taken full advantages of the planning support system which integrates the BUG model, BEAM database, Virtual Brisbane, and existing urban planning and infrastructure management practice. The Brisbane's planning support system has the ability to provide an integrated solution that is not only visually powerful but also rigorous in analysis. The ability to pre-visualise future growth factors and the potential impacts of proposed development is a vital tool in the planning of future urban infrastructure. With this planning support system, reliable information and data are provided to the urban planners and decision makers to formulate realistic vision, provide better planning outcomes, policy and infrastructure that adequately address the local needs and achieve sustainable spatial forms.

Figure 4 illustrates the planning support system of Brisbane City Council. The operation framework of the system consists of the BUG model, urban infrastructure database, BEAM database, Virtual Brisbane, and other Council's spatial databases. Demand and capacity analysis and development projections are now being carried out in a coordinated manner between different infrastructure providers and urban planners. Reliable information and data are provided to the decision makers to formulate a realistic vision and achievable development targets for the city. Strategic and neighbourhood planning are being carried out based on dynamic information of the integrated planning support system. Sustainable urban development and infrastructure management is achieved as a result of a clear understanding of the interconnected relationships of the local areas, rather than as a result of assumptions based on abstract values.

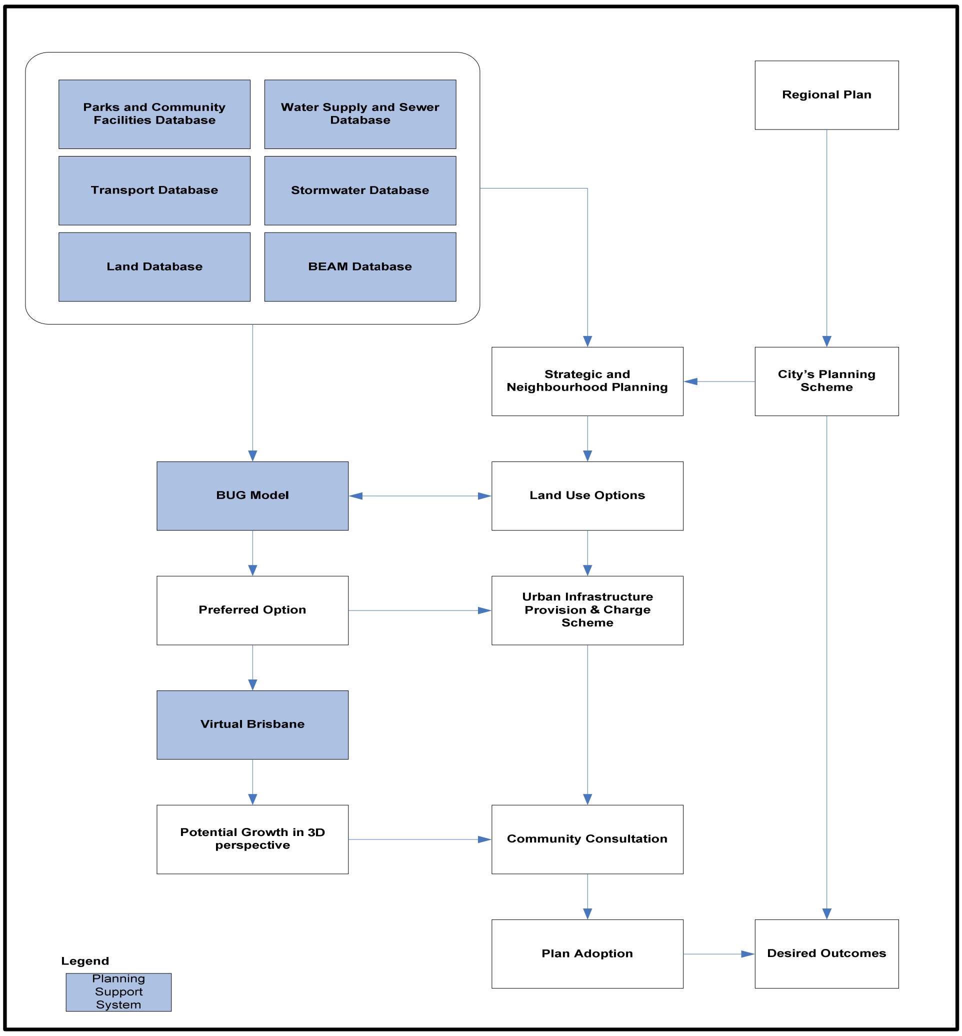

Figure 4: Planning support system of Brisbane City Council

6 Conclusion

In conclusion, the roles and responsibilities of local governments are expanding beyond just the daily operational maintenance of a city and the assessment of property development applications. Local governments are now also required to undertake economic planning; manage urban growth; be involved in major national and state infrastructure planning and even engage in achieving sustainable development objectives. Delivering sustainable urban infrastructure and maintaining liveability of a city become increasingly important for local governments around the world.

The evolution of computer and internet technologies in the past decades has made public information more accessible and significantly improved the knowledge transfer process between government and the community; as a result, the performance of elected local officials and governments are constantly under the media spotlights. Local communities from both developed and developing countries have demanded greater transparency in public sector reporting, and there have been numerous examples of public inquiries regarding the poor performance and ill-informed decisions of local elected officials.

This paper has provided a brief insight of the Brisbane City Council's new urban planning framework which is based on a reliable and dynamic planning support system. The BUG model, BEAM database and Virtual Brisbane are vital parts of Brisbane City Council's planning support system. This planning support system has proven initially successful as an integrated knowledge management tool for improving the effectiveness and efficiency of infrastructure management, urban planning and community engagement through better knowledge management processes. It has also improved the accountability and transparency of the planning and delivering of infrastructure by providing an integrated development forecasting framework to facilitate sustainable urban development.

The Brisbane City Council's planning support system is constantly evolving and integrating with new database, system and information to improve the planning, community engagement and development processes. Excellent urban planning and development assessment processes, transparent community engagement program and innovative planning supporting system are the key elements to ensure sustainable and well planned future of Brisbane.

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